Scale setting in V+jets production

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Based on work in collaboration with Bjoern Lange

0905.4739

Motivation

- LO calculations are by now very easy
- Despite much progress on higher order calculations, many distributions still only available at LO
- Well known that distributions can have very different shape at LO and NLO
- For many processes, dominant effects at NLO arise from terms enhanced by logarithms of large ratios of scales

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Can we resum these large logarithmic terms?

Why just scale setting?

- Large corrections arise from large logarithmic terms
- Can be resummed using IR evolution equations or effective field theory methods (SCET)
- Has allowed for much better predictions for many observables (thrust, Higgs production, Drell-Yan, ...)
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If yes, what accuracy can be achieved?

Outline

- Quick overview of log resummation using SCET
- Case study: $pp \to Vj$
- Adding one extra jet: $pp \to Vjj$
- Discussion about adding additional jets

Log resummation using EFT's

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Derive RG Equation, by taking μ d/dμ

$$\mu\frac{\mathrm{d}}{\mathrm{d}\mu}\frac{\mathrm{d}\sigma_n^{\mathrm{LL}}(\mu)}{\mathrm{d}\Phi_n} = \gamma_n(\mu)\,\frac{\mathrm{d}\sigma_n^{\mathrm{LL}}(\mu)}{\mathrm{d}\Phi_n}$$

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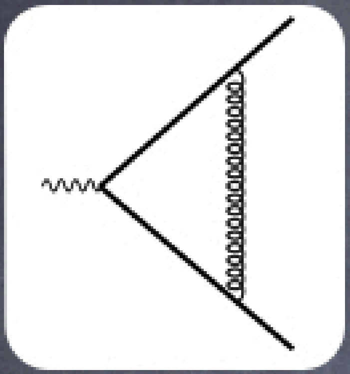
What do large logs have to do with UV of theory?

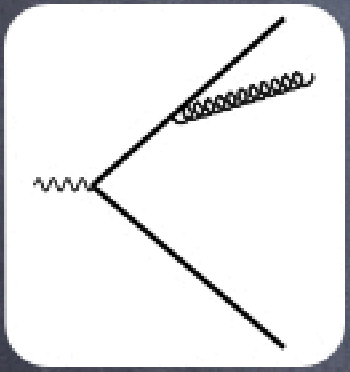
Log resummation using EFT's

Logarithms related to IR divergences in theory



Divergences from loop integrations

$1/\varepsilon + \ldots$



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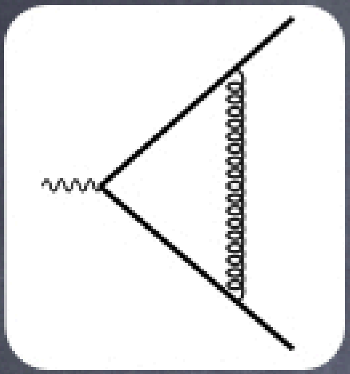

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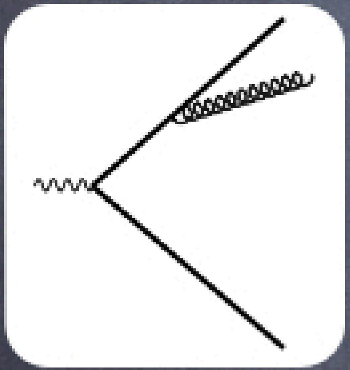

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Restrictions on phase space give rise to logarithmic remainders $0<k_g<\mu \Rightarrow -1/\varepsilon + \log(\mu)$

$\sigma_V + \sigma_R = \log(\mu) + \ldots$

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IR dependence of full theory can be extracted from UV dependence of EFT

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Q

μ_1

$\ldots$

μ_n

Λ

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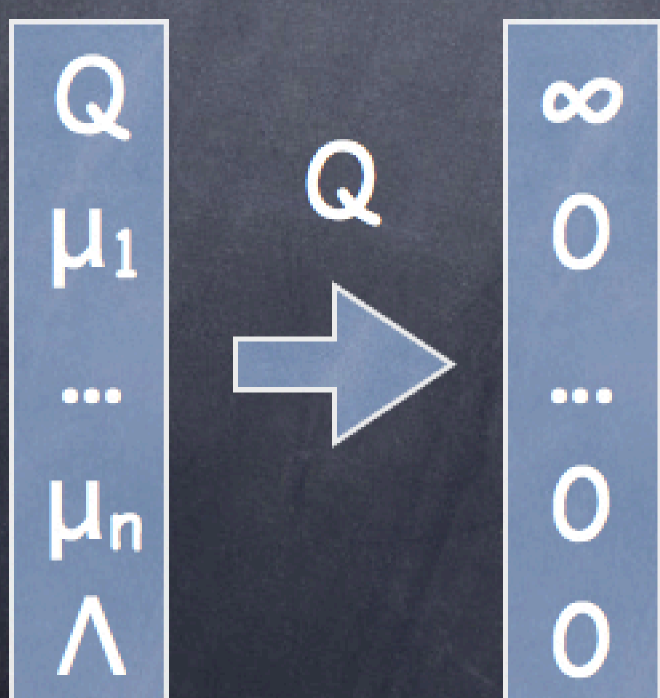

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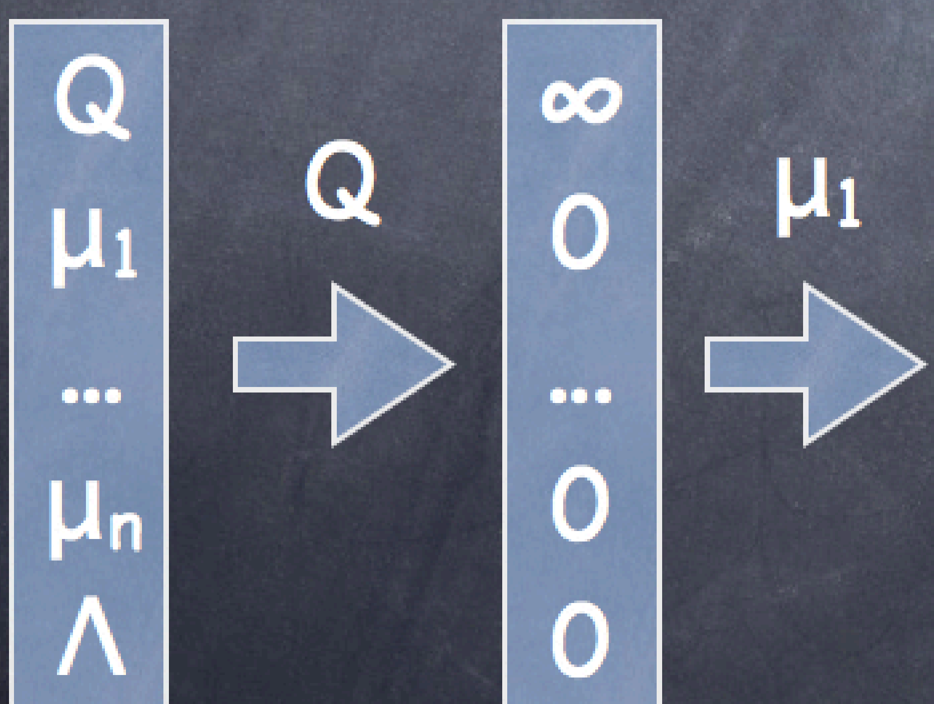

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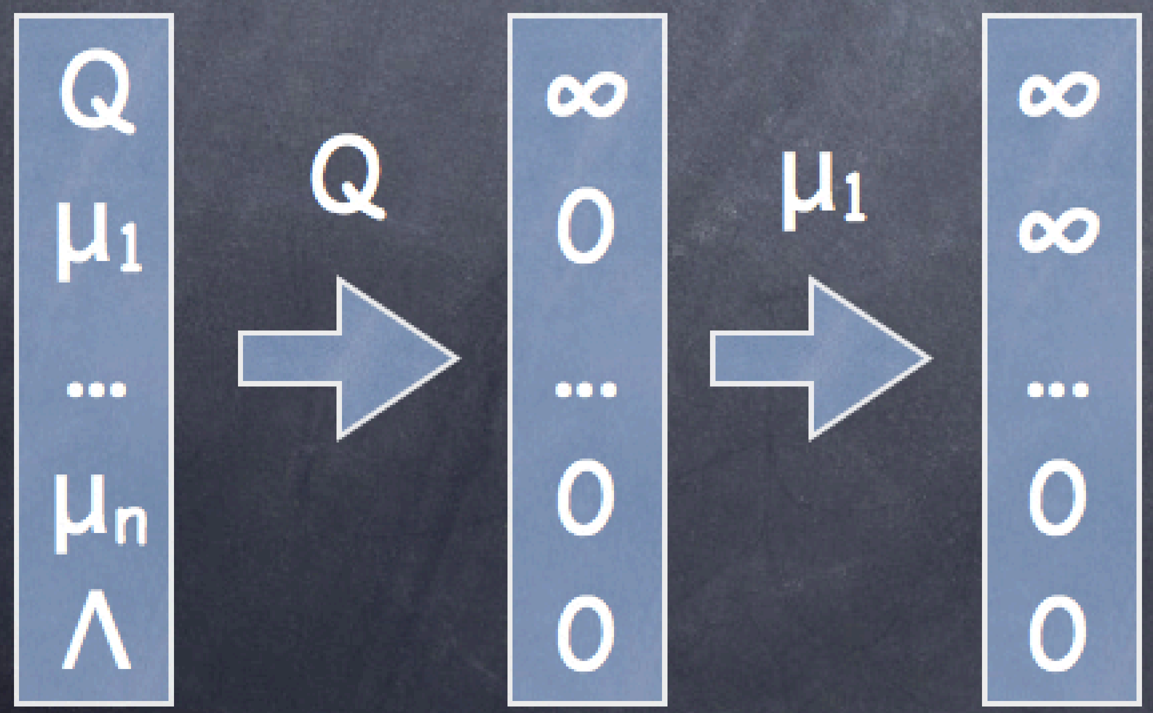

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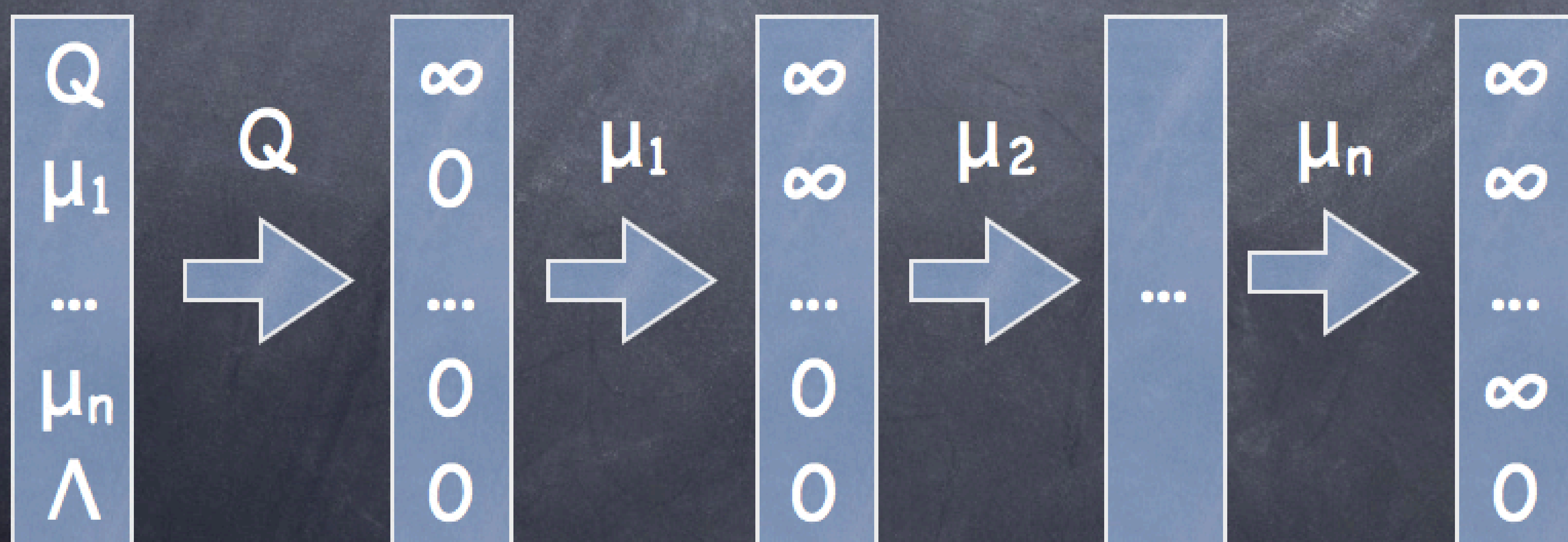
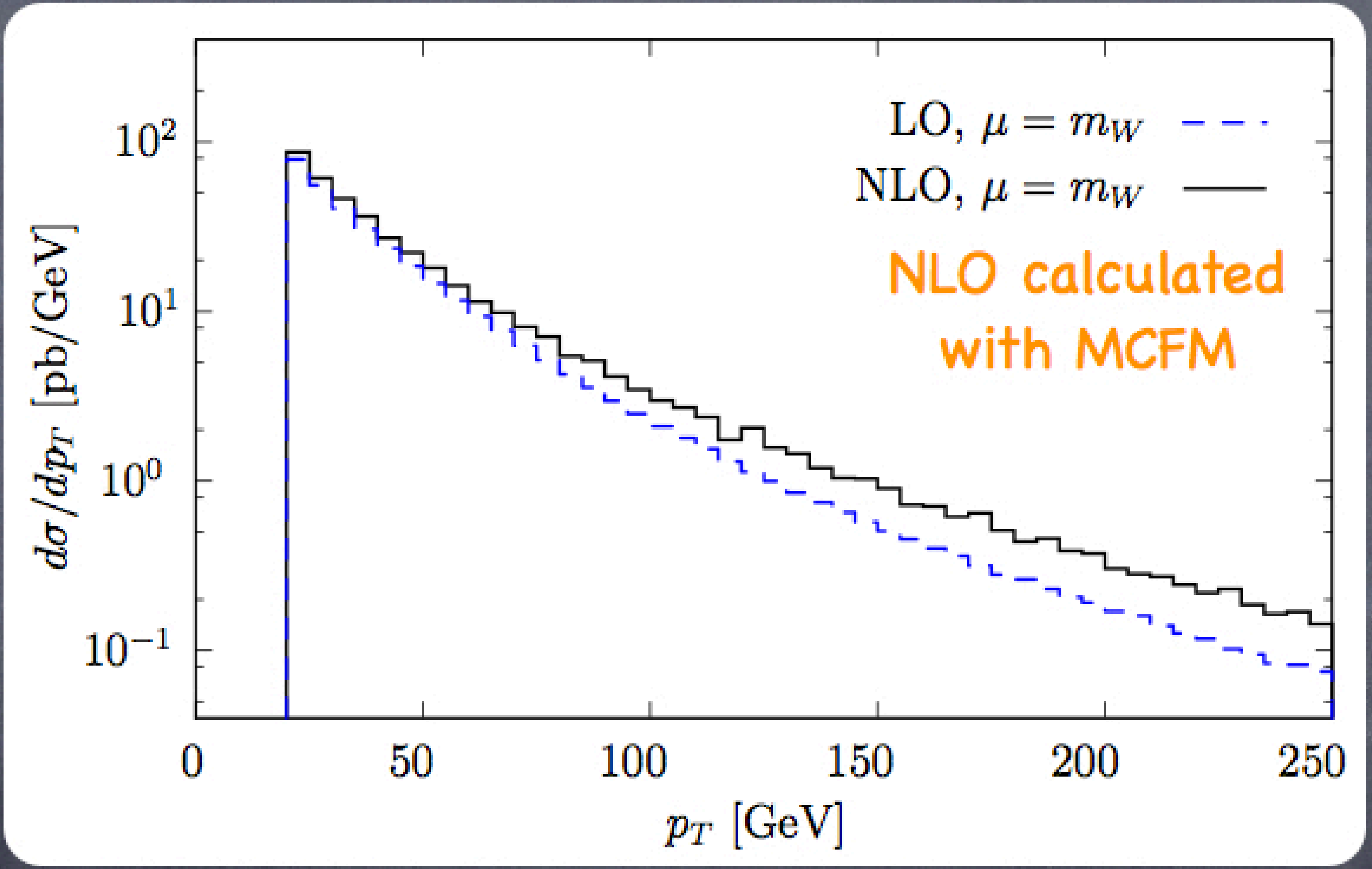
- Repeat to remove all scales



Case Study: pp→V+j

Study the p_T distribution at large p_T



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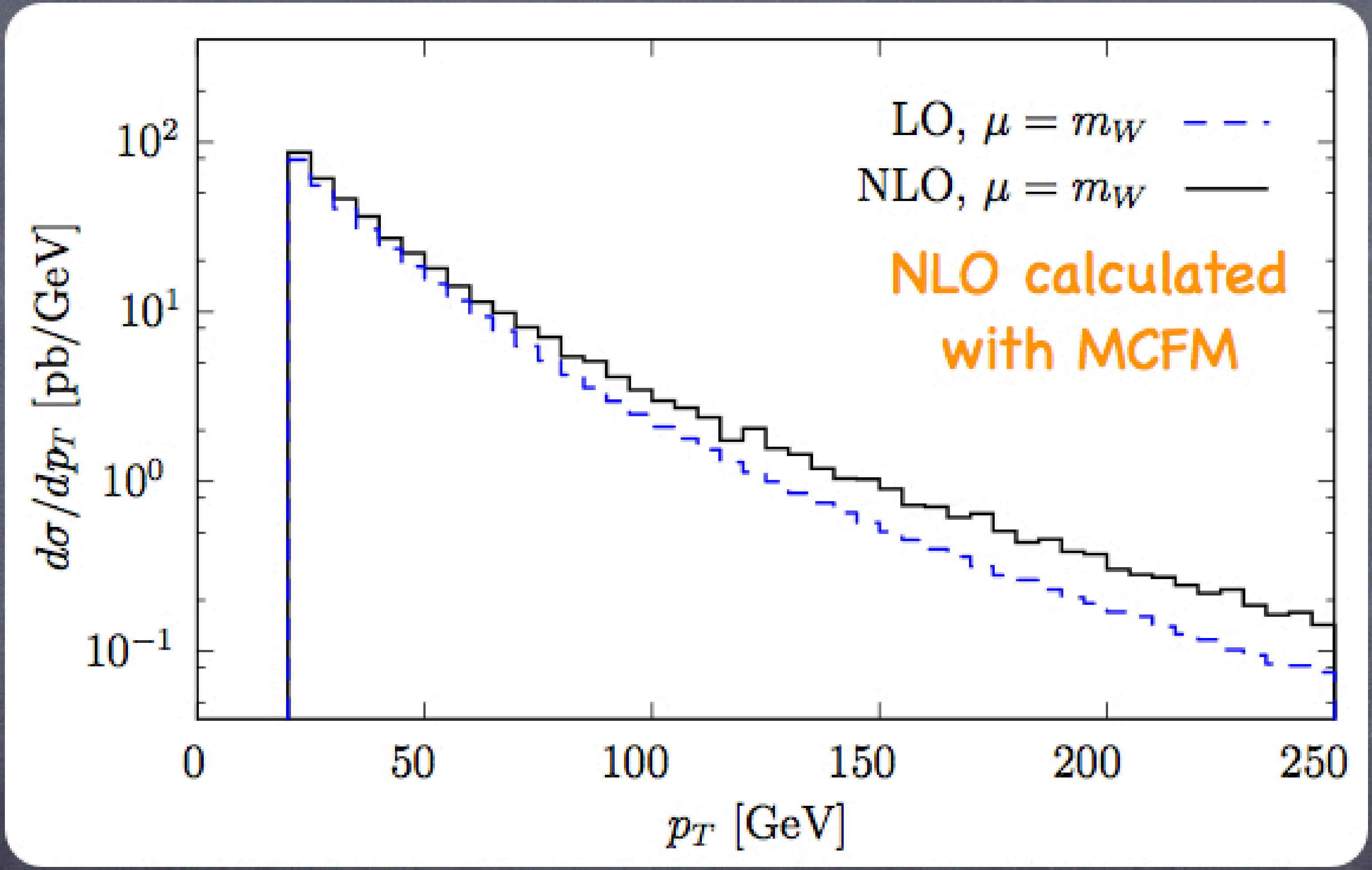


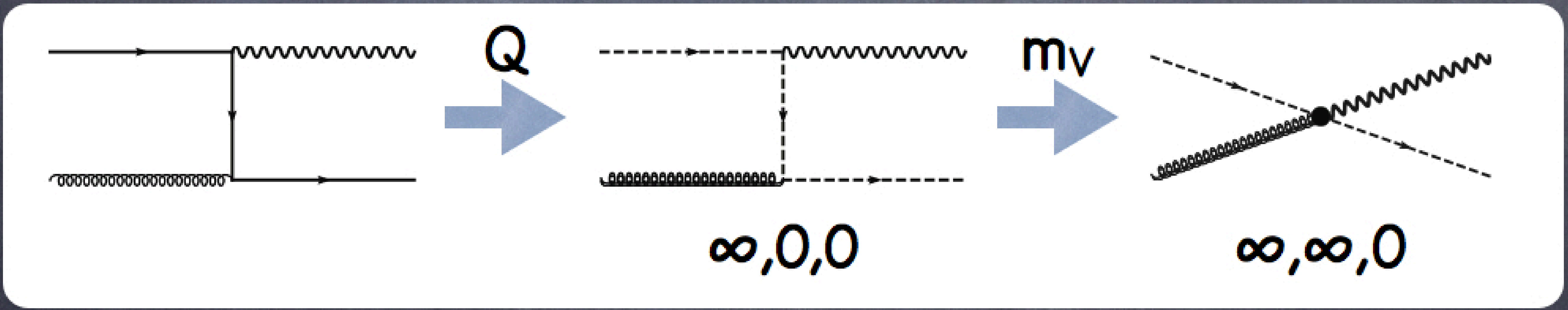
Can these diverging curves be reconciled using resummation?

Case Study: pp→V+j

Study the p_T distribution of jet, in region $p_T \gg m_W$

Three scales in problem: $p_T \gg m_W \gg \Lambda$

Integrate them out one by one



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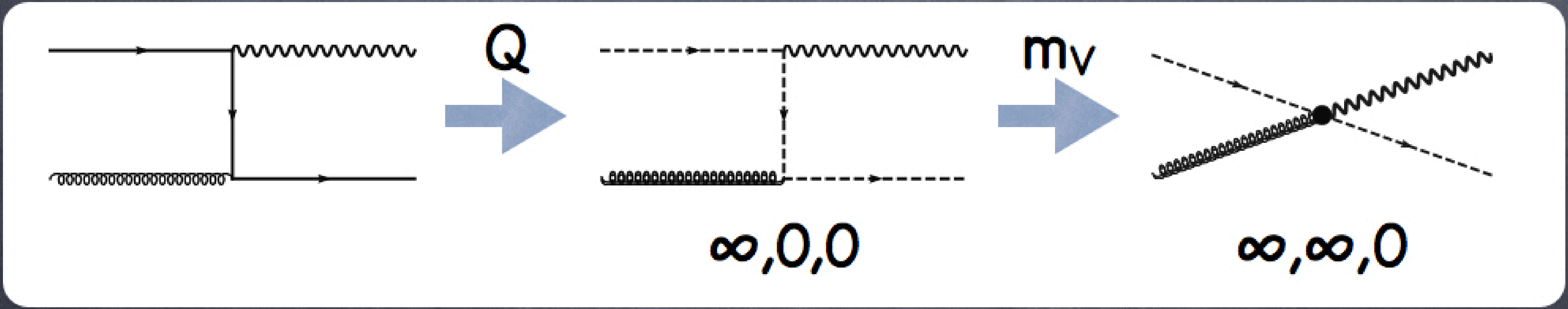

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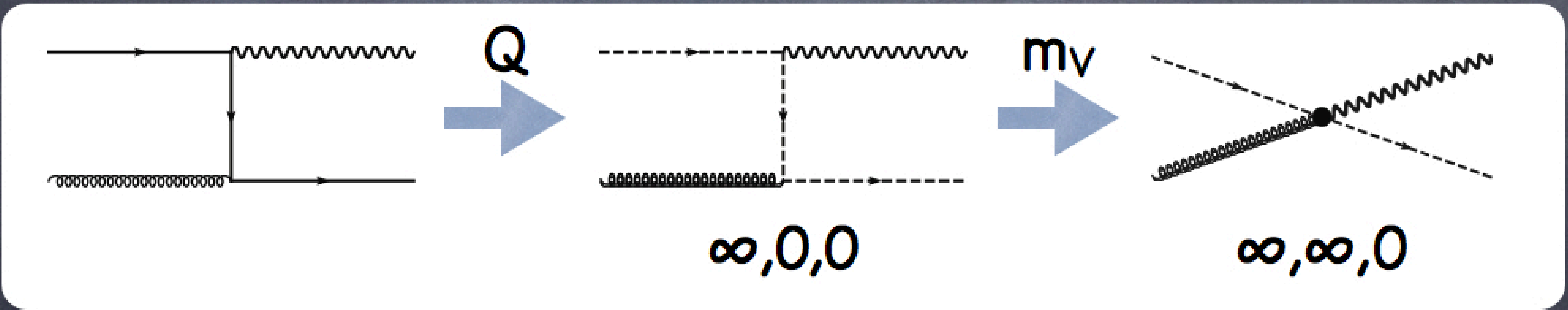

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But what is really happening at scale m_V?

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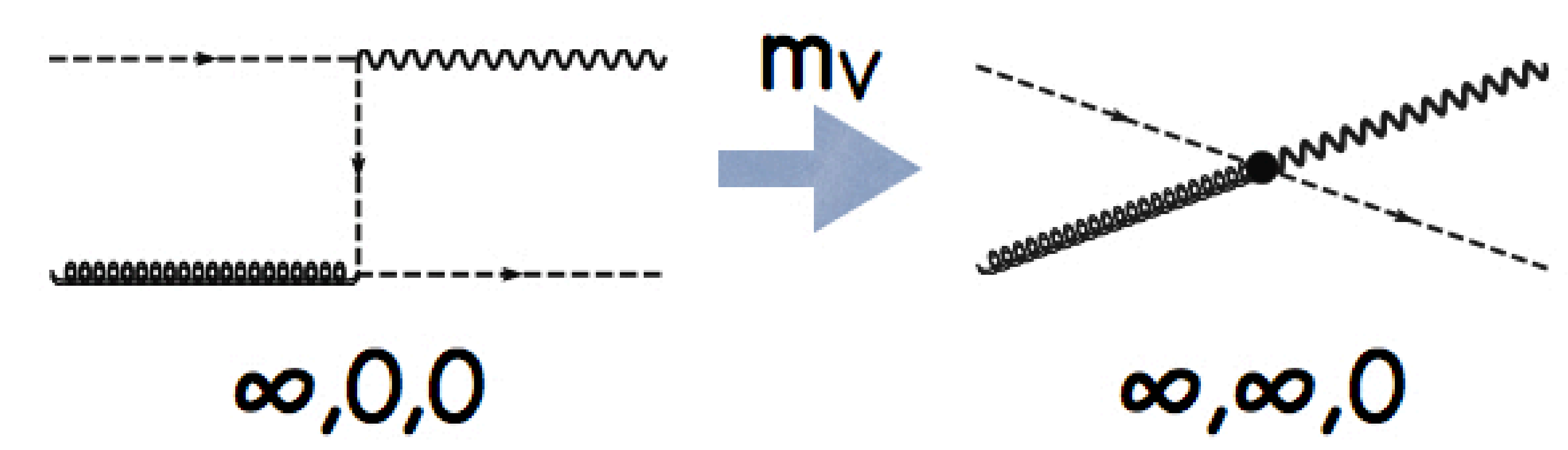

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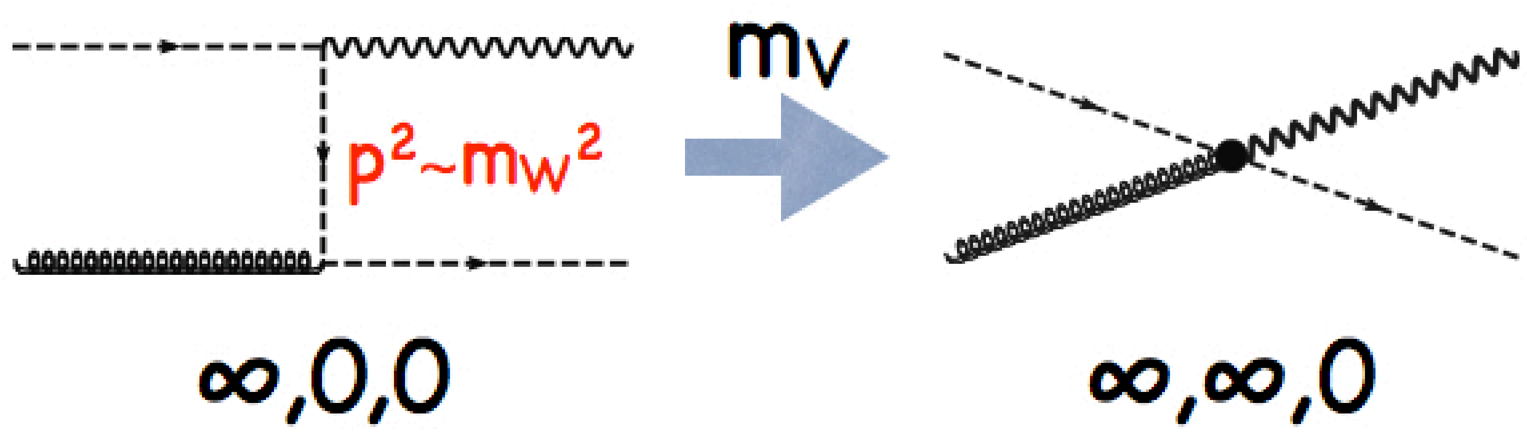

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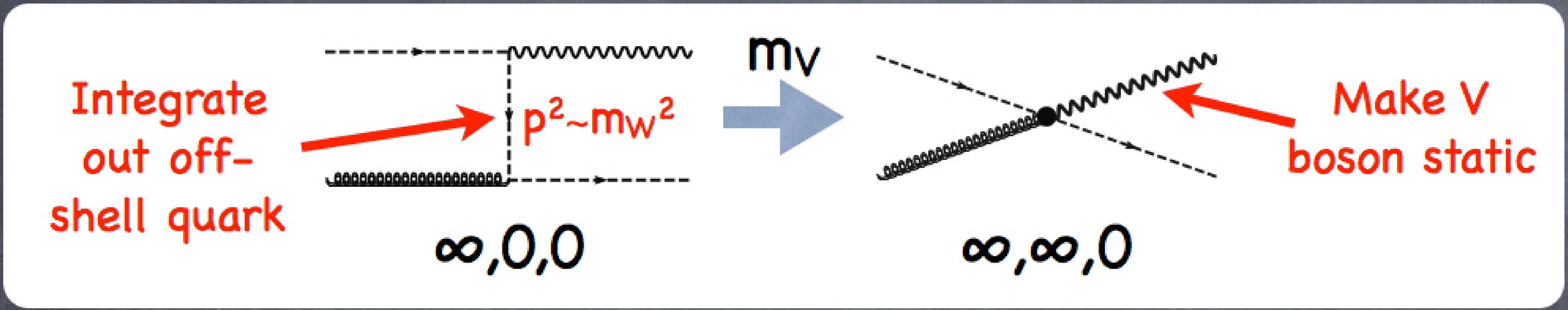

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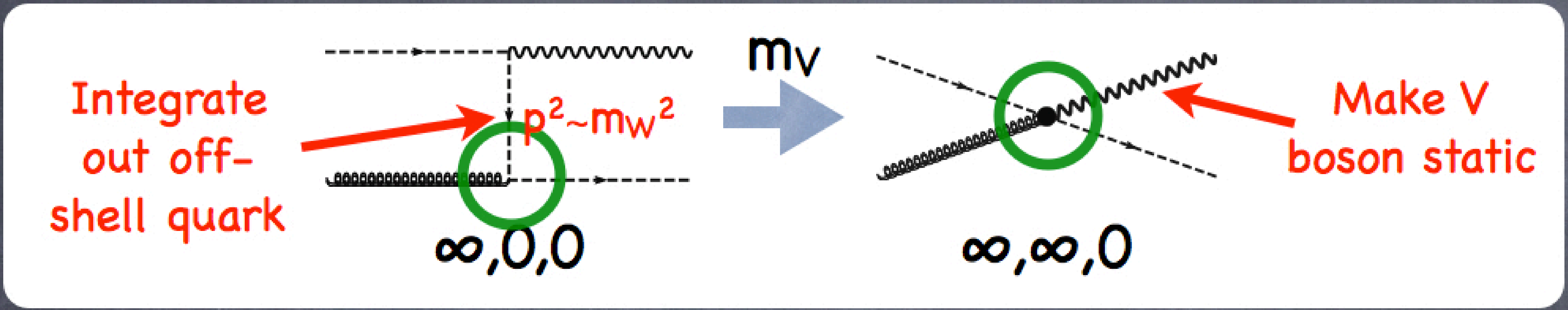
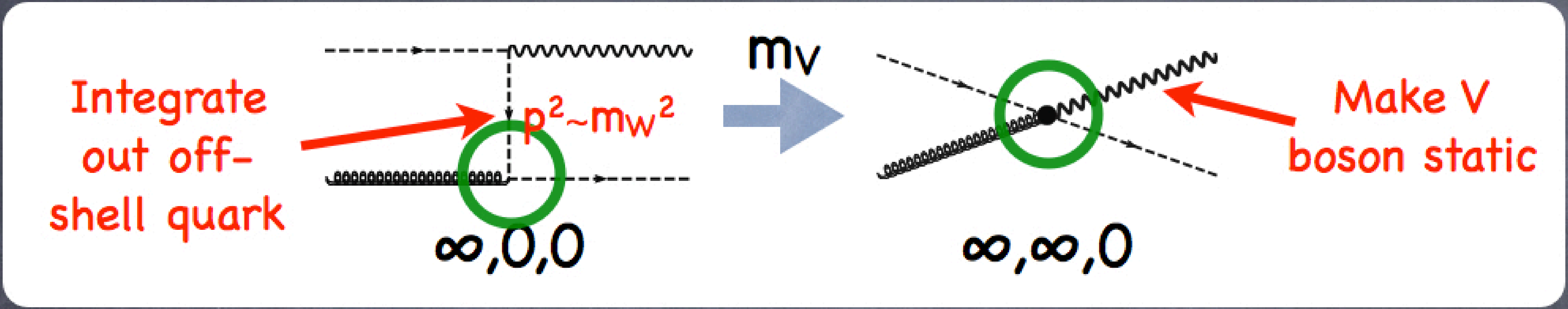


Two different operators, but both have same strongly interacting field content

Case Study: $pp \to V+j$



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Implies that the leading UV divergences are same for both operators

LL running above m_V and below m_V the same

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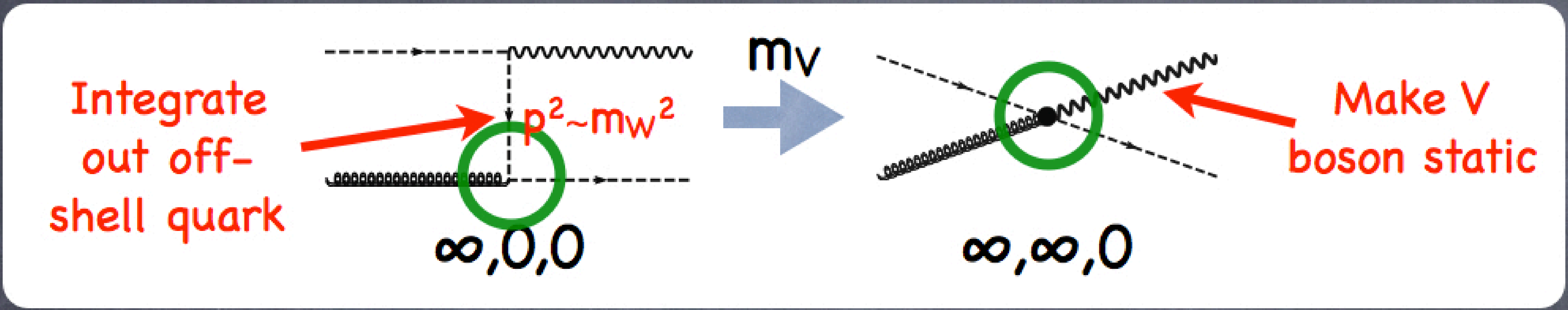

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No leading log dependence on scale m_V

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Only relevant scales at LL are Q and Λ

Running in EFT is given by AP evolution kernels

All leading logs resummed by choosing $\mu_F = p_T$

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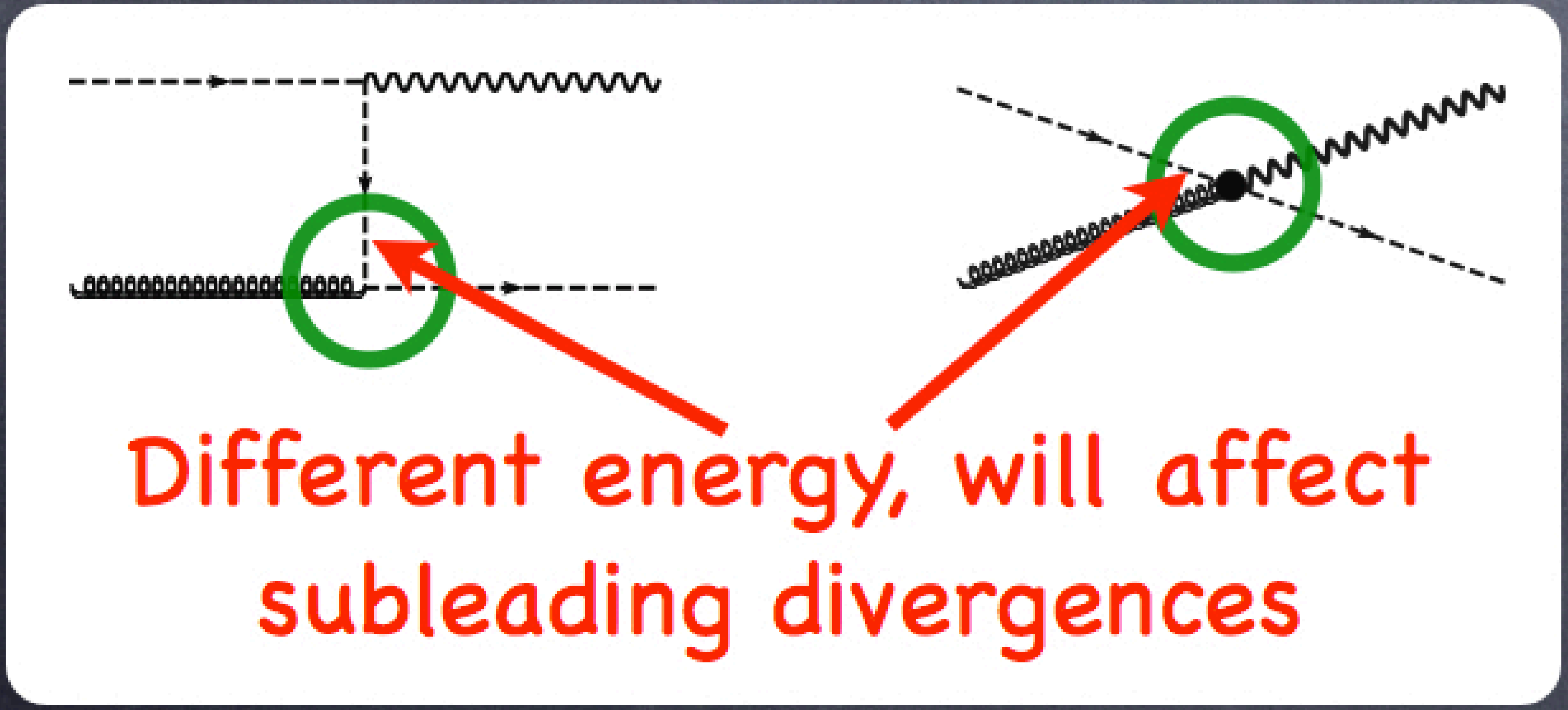

Results only correct at LL accuracy, does not hold beyond

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- This is of course well known
- Most NLO calculations use a "dynamical scale" $\mu^2 = p_T{}^2 + m_W{}^2$
- Important result is
  - This can be shown to be correct at LL accuracy
  - Can be shown through a simple EFT analysis

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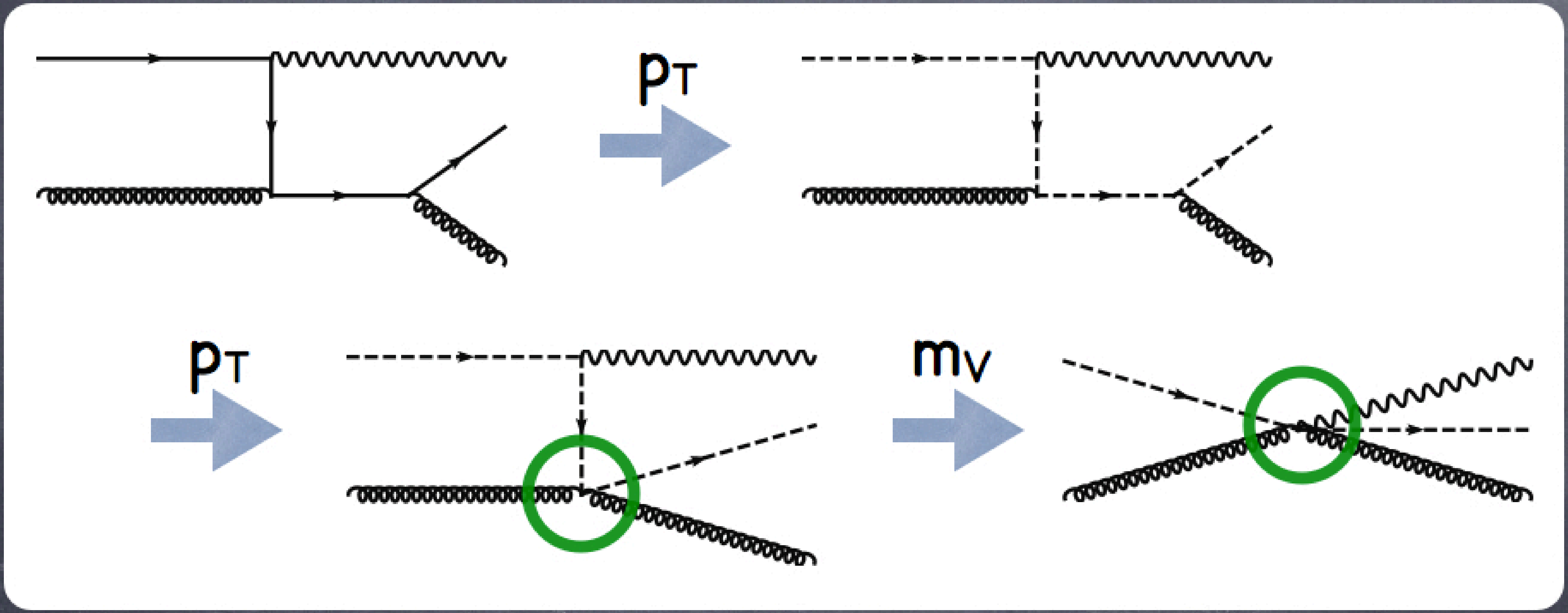
Can extend this result to higher number of jets and eventually to very different processes

One extra jet: pp→V+jj

Consider $Q \sim p_T \gg m_W \gg \Lambda$



As before, nothing happens for LL at m_V

Both operators have same strong fields

Should again choose $\mu_F = p_T$

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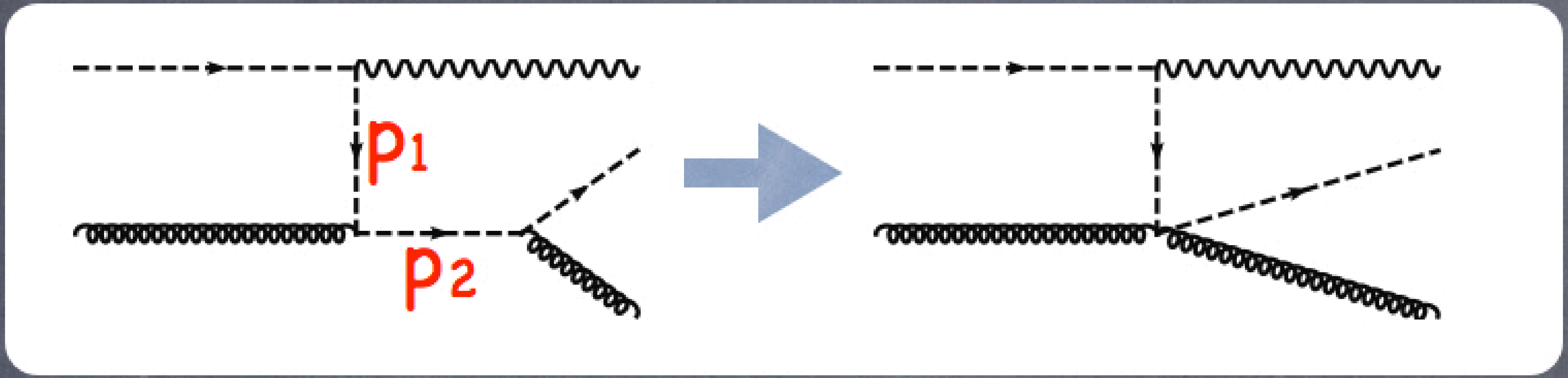
One side note:



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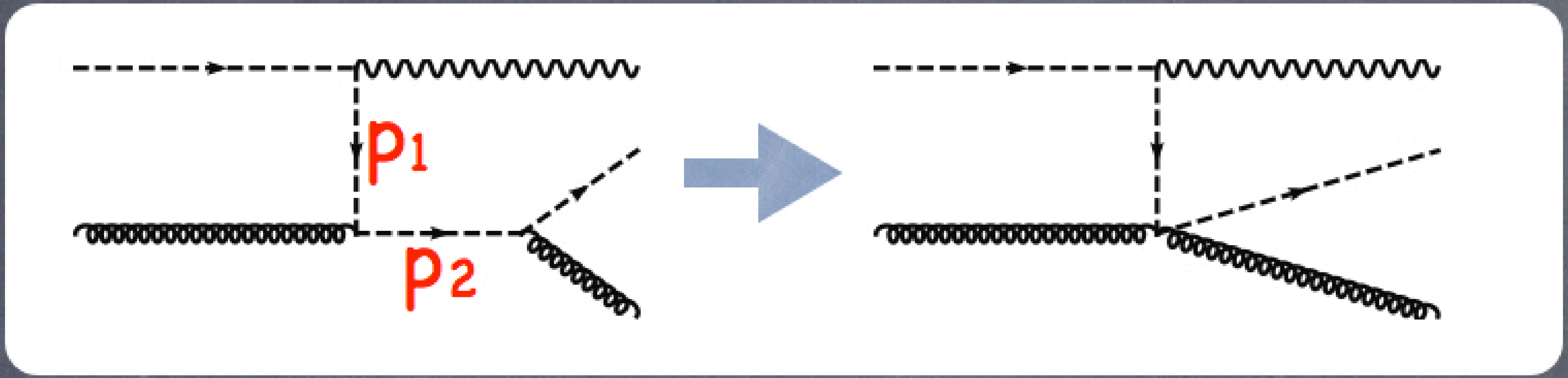

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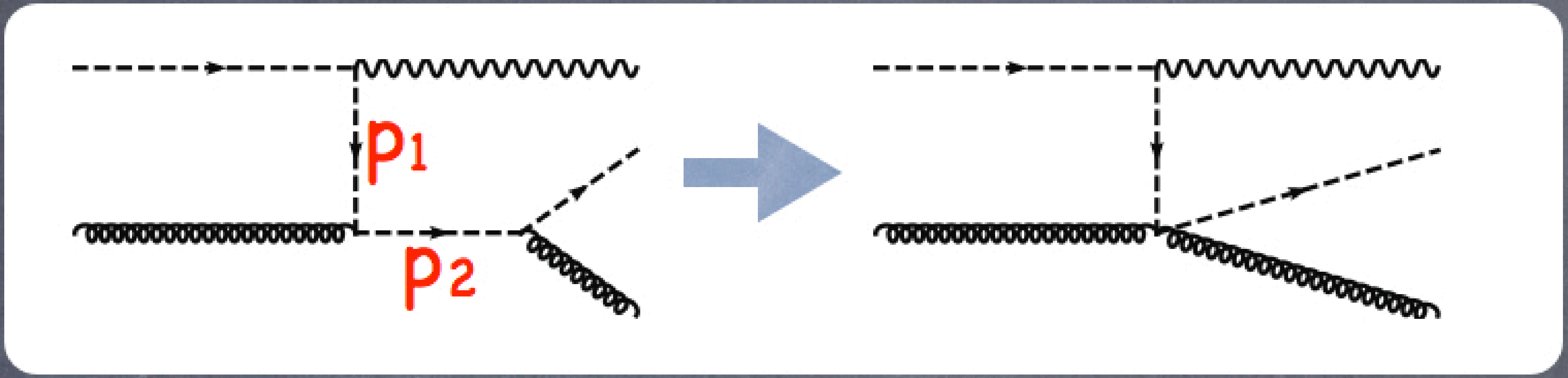

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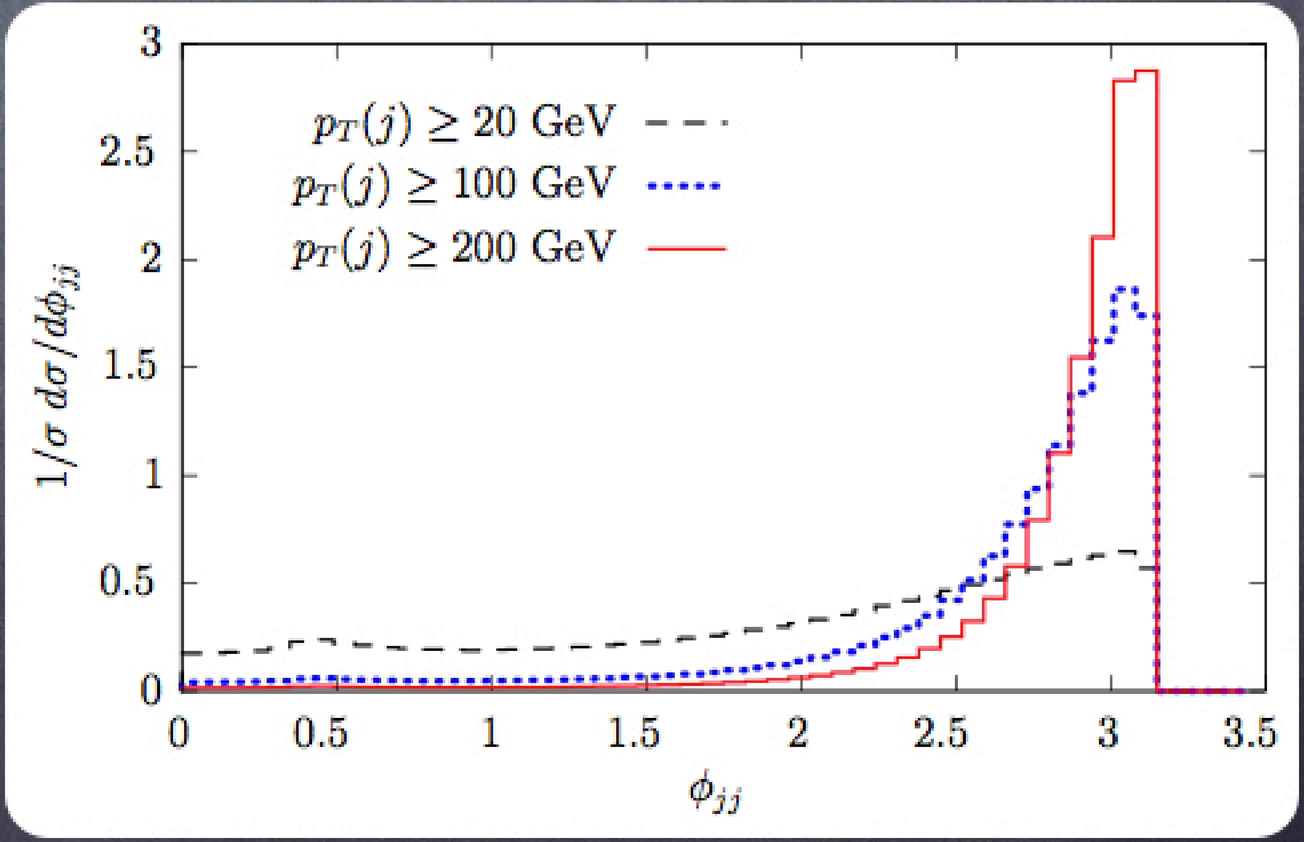

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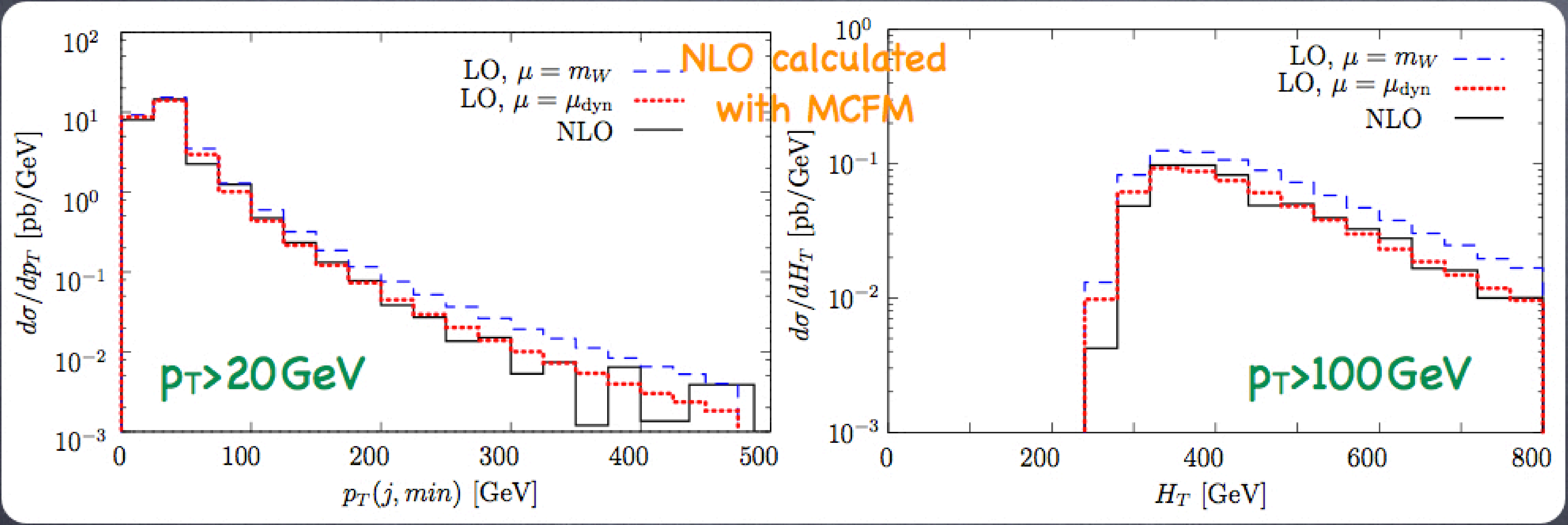
Compare again to fixed order calculations



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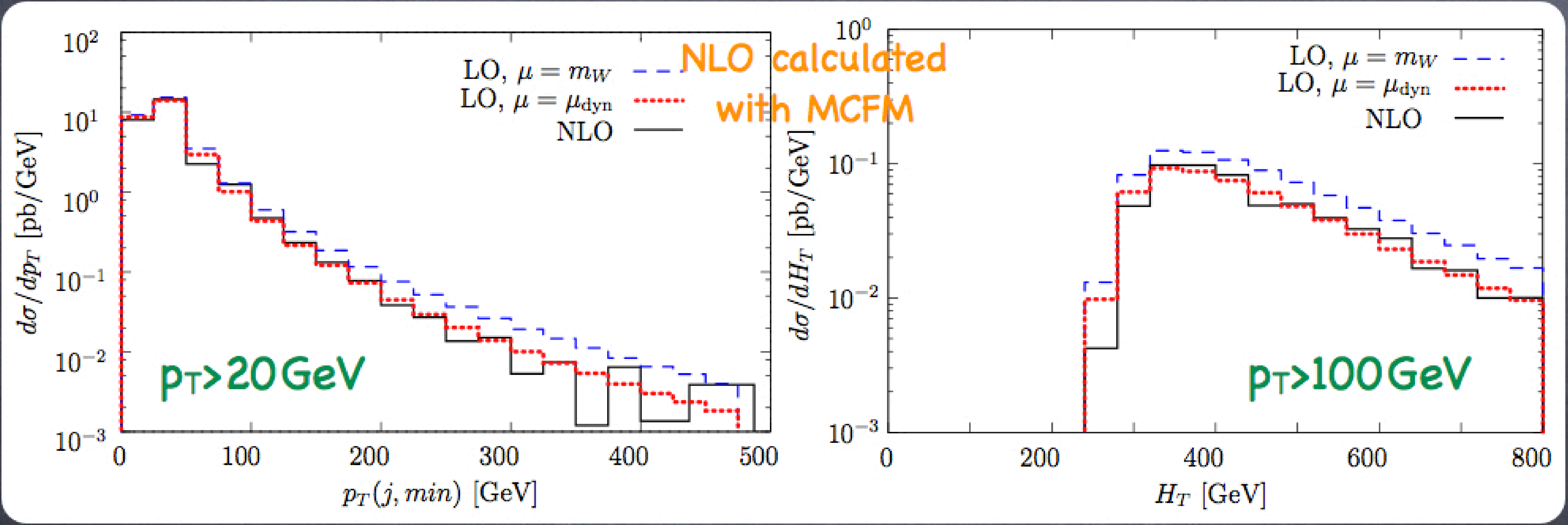
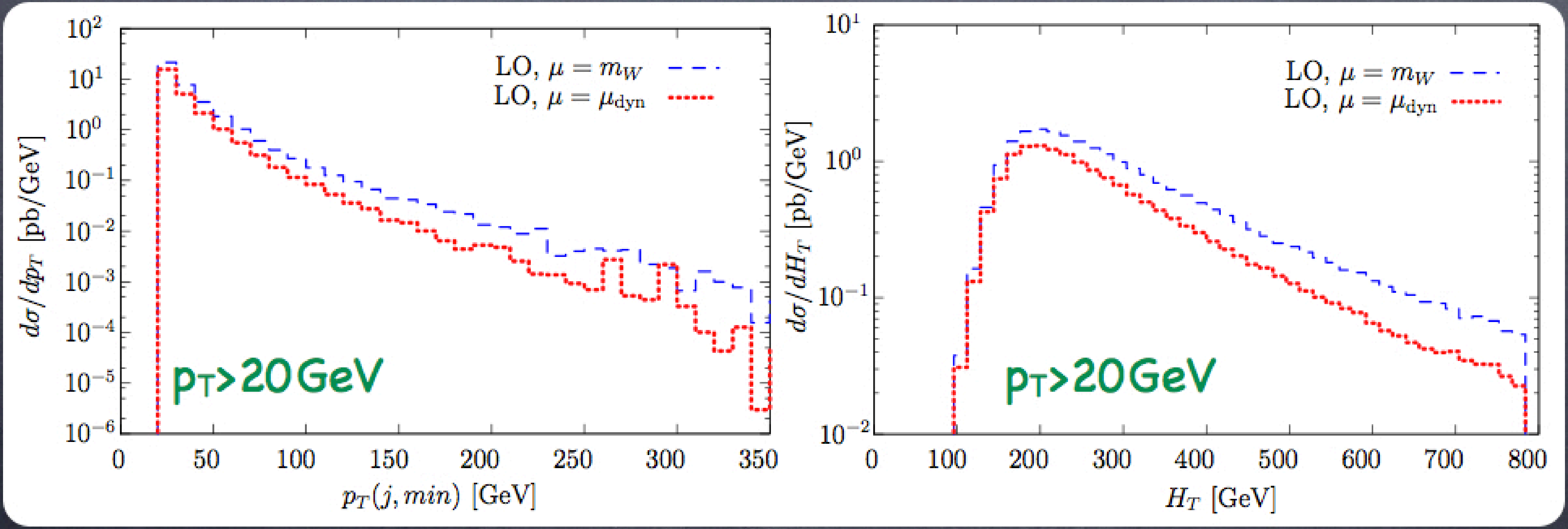


Again, with new scale choice, much better agreement between LO and NLO calculations

Adding extra jet: pp→V+jjj

- Nothing in this discussion knew anything about the number of final state jets
- In general, should choose scale μ=Q_{QCD}, where Q_{QCD} denotes scale at which jets are produced



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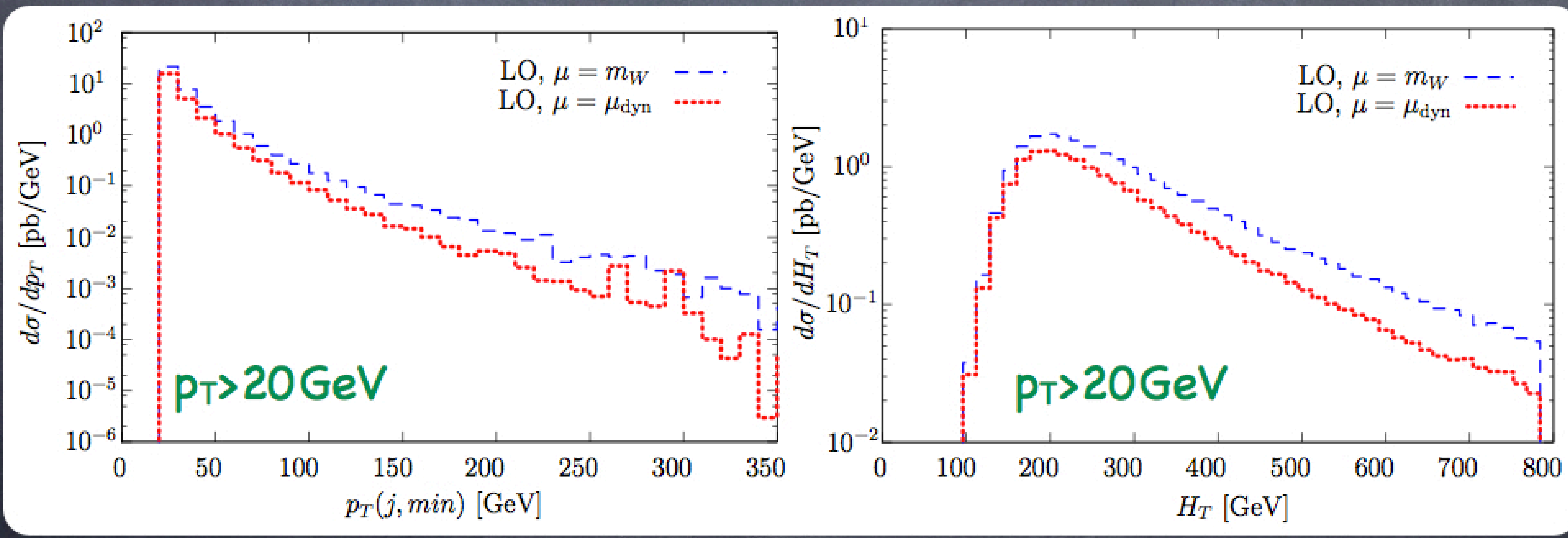


At time of our paper, no NLO calculation available

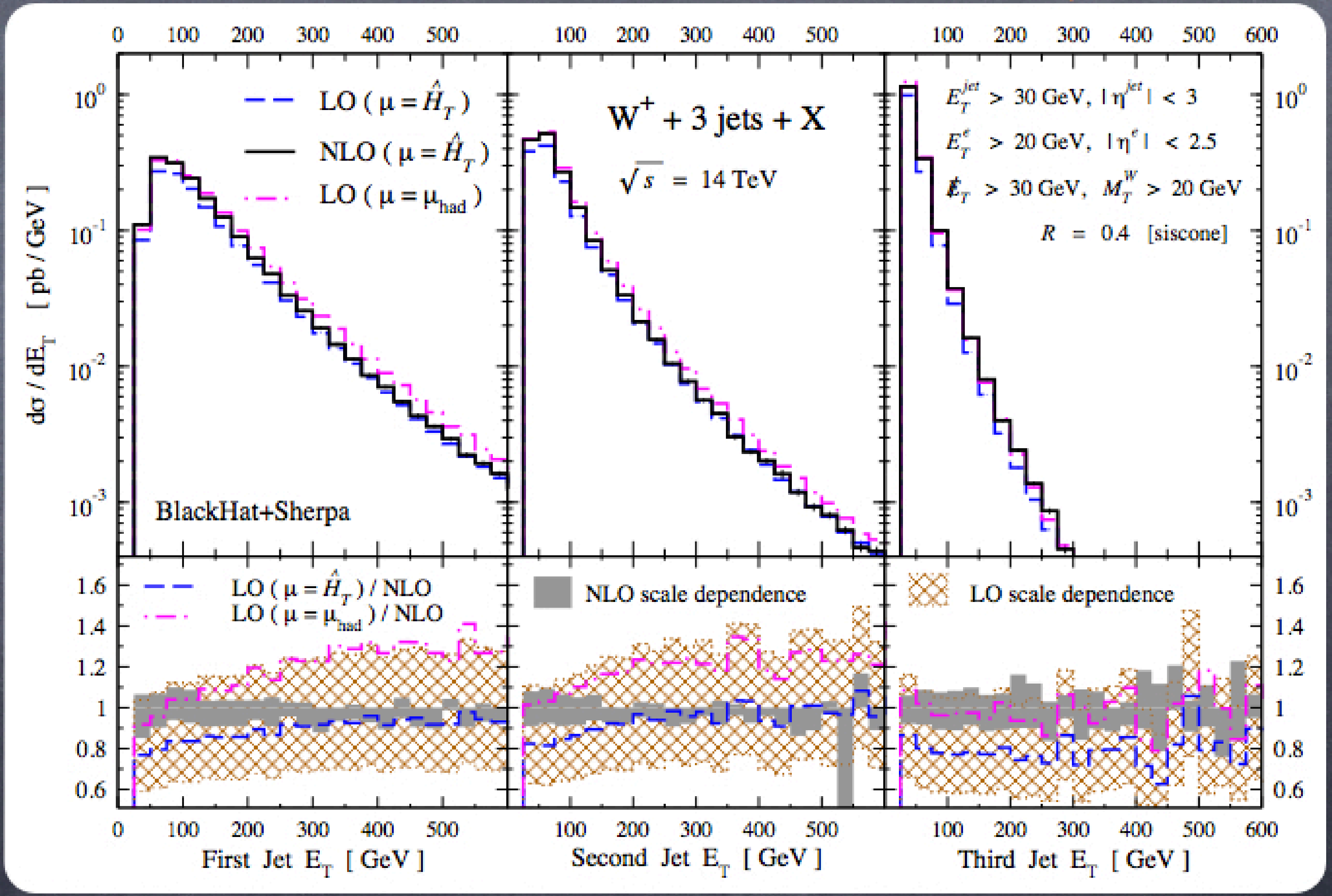
Precise scale choice

NLO calculations now exist!

Blackhat, 0907.1984

Clearly, there are various ways to define Q_{QCD}

Can not use EFT's right now to prefer one over another



Conclusions

- Large logarithms often plague fixed order calculations
- In some cases, large logarithms arise only from unfortunate scale choices
- EFT's allow to understand logarithms and therefore appropriate scale choices naturally
- Have given examples in pp→V+jets where proper scale choice can significantly improve convergence of LO→NLO
- Works very well, but precise scale choice can not be predicted
- Expect that same ideas hold for many other processes